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Ecosystem Services Assessment Methods for Integrated Processes of Urban Planning. The Experience of LIFE SAM4CP Towards Sustainable and Smart Communities

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Abstract. Evaluation of Ecosystem Services (ES) supports the knowledge and the ability of politicians, administrators, planners and stakeholders to define urban regeneration strategies rather than sustainable spatial planning and design practices responding to climate change conditions and addressing the wellbeing of local communities. The analysis of ES allows for the study of the relationship between urban morphology and land cover/land use to define priorities that maximize the ability of urban systems to deliver multiple benefits (e.g. to store carbon and improve air quality). The recent research innovations made by DIST – Politecnico di Torino for LIFE + Program SAM4CP (2014-2018), moves towards the implementation of a theoretical and practical framework that integrates the process of planning and decision making with the analysis and assessments of ES. The framework has been conceived to support Municipalities to settle policies and monitoring procedures oriented at defining Nature-Based solutions (e.g. restoration strategies) assuming an urban ecology perspective. The project aims at providing a digital tool – a Simulator delivered to Local authorities– to evaluate the ES assessment in different land use scenarios to determine the environmental and economic costs, or benefits, that arise from alternative planning configurations. The evaluation of ES in a case of study area shows that the effective integration of ES evaluation and planning actions is a straightforward method that create awareness and increase the sustainability during decision-making phases for the planning process. The Simulator is available for free on the project website – www.sam4cp.eu – to allow administrators and public officials, as well as spatial planners, interested in such a kind of evaluation, to experiment and apply this methodology.

1. Introduction

1.1. Environment and spatial planning

In the last decades, the environmental issue re-emerges with a different, more dramatic impact, that considers the measure of how contemporary cities and territories are exposed to the dangers caused by climate change and its effects on health and well-being, combined with other physical risks (seismic activity, damaging hydrogeological events, air pollution) and, above all, those linked to the global economic crisis and that of public finances, the emergence of new inequalities, poverty and social tension.

Facing with a new ‘urban question’ the issue of “land suitability” arises with new and a broader demand for a spatial assessment that recognise, above all, greenfield sites and limit their consumption



re-defining their planning contents. Therefore, a new point of view with a critical perspective is emerging, which demonstrate an attention to see the ‘project of the land’, in new terms. Assuming this perspective, greenfield sites become a new model that focuses a deep-rooted review of urban and environmental policies, that are at the base of a planning renovation. The growing interest and commitment towards ecosystem services (ES) are therefore based on the awareness that we need to harmonize the maintenance – or the reconstitution – of our natural capital with the permanent capital constituted by the settlement systems.

A necessary condition for modern-day town planning actions is the availability of new and more comprehensive knowledge repertoires, more diverse network of skills, which can work with each other to the benefit of human well-being. [1] (Giaimo Barbieri 2018).

1.2. Simulsoil, an introduction

Ecosystem Functions are the capacities and processes of natural components to deliver goods and services that directly or indirectly satisfy the human’s needs. On the base of this assumption, the Millennium Ecosystem Assessment (MEA) defined the multiple benefits and goods that natural ecosystems deliver to humans as ESs. Land use changes in the short, medium and long period affect ESs decreasing their biophysical value but also reducing the economic amount of the Natural Capital available.

Simulsoil is an informatics easy-to-use tool that analyses the ESs trend induced by land use changes in a selected territory and then quantifies the total amount of the Natural Capital and its variation along different time thresholds. It gives the possibility to a non-expert ESs analyst and various users (e.g. planners, administrator or interested citizens without a proper skill on Geographic Information System rather than an ecology/environmental preparation) to generate a simulation of a predicted land use change and its environmental effect using few inputs. Simulsoil is a product of the European project LIFE SAM4CP which promoted a broad use of tools and software aimed at increase the awareness of planners and public administration at the local level of the importance of soil ESs. The software works as a standalone configuration using QGIS2.18.15 configured by the plugin “Simulsoil”, and it is freely downloadable from the LIFE SAM4CP website in the section “Simulator” (see <http://www.sam4cp.eu/en/simulsoil/>). It has been designed to facilitate and favour sustainability in urban planning, especially for municipalities engaged in a continuous process of an upgrade of the local zoning forwarding a better environment for the citizen with actions to limit, mitigate or compensate for soil sealing.

The tool provides information on different ESs primarily using a Land Use Land Cover (LULC) database that the user can directly upload by different “scenarios”. On the base of the LULC configuration, Simulsoil automatically harmonises the complex processes and algorithms to generate spatial maps of ecosystem provision using the algorithms of InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) thus facilitating the ESs assessment only assigning to the user one input variable: the LULC configuration [2–4].

Simulsoil automatically deliver eight different ES maps setting the input LULC variable: Habitat Quality (InVEST), Carbon Sequestration (InVEST), Water Yield (InVEST), Sediment Retention (InVEST), Nutrient Retention (InVEST), Crop Production (Simulsoil elaboration), Crop Pollination (InVEST) and Timber Production (Simulsoil elaboration). Each user can decide which land use configuration analyse: the actual land use configuration rather than a different alternative (predicted or unpredicted) configurations generating a comparative ESs analysis between the layers. Simulsoil delivers automatically the eight output ESs layers detailing their biophysical and economic value thus creating a quantitative report. The utilization of the tool for comparative analysis between different LULC configuration allows the user to simplify the evaluation process of plans and projects during the Strategic Environmental Assessment (SEA) [5–7] contributing to provide an adequate support during decision-making processes for land use definition forwarding a real sustainability in planning.

Simulsoil can be directly installed in a home station. The download includes also a data library of the national and local input parameters for data processing.

2. Methodology

2.1. Which Ecosystem Services?

As earlier mentioned, Simulsoil uses eight ESs: Habitat Quality (supporting), Carbon Sequestration (regulative), Water Yield (regulative), Nutrient Retention (regulative), Sediment Retention (regulative), Crop Production (provisioning), Timber Production (provisioning) and Crop Pollination (supporting).

According to with the most famous international ESs classification [7,8,9], Simulsoil covers a broad range of categories (supporting, regulative and provisioning) while the cultural and recreation potential where not considered by the research as planned initially (for research feasibility reasons). Nevertheless, it is crucial to be aware that a full ESs assessment requires at least one or two of the abovementioned categories to cover the broadest spectrum of possible ESs [10–12].

Hereafter, according to the InVEST guide of Sharp et al., a summary of the services is reported:

- Habitat quality (HQ): is considered a proxy of Biodiversity for its supporting nature. LULC is analysed in conjunction with threats. The model habitat quality and rarity estimate the extent of habitat and vegetation types across a landscape, and their state of degradation. Habitat quality and rarity are a function of four factors: each threat's relative impact, the relative sensitivity of each habitat type to each threat, the distance between habitats and sources of threats, and the degree to which the land is legally protected. Output: index from 0 to 1.
- Carbon Sequestration (CS): the model uses maps of land use and stocks in four carbon pools (aboveground biomass, belowground biomass, soil, dead organic matter) to estimate the amount of carbon currently stored in a landscape or the amount of carbon sequestered over time. Output: tons of carbon stored in the area
- Water Yield (WY): the model identifies how much water yield or value each part of the landscape contributes annually to the streams. The model use data on average annual precipitation, annual reference evapotranspiration and a correction factor for vegetation type, root-restricting layer depth, plant available water content, land use and land cover, root depth, elevation and saturated hydraulic conductivity. The biophysical models do not consider surface-groundwater interactions or the temporal dimension of water supply. Output: litres of water retained in the area.
- Nutrient Retention (NR): the nutrient delivery model maps diffuse nutrient sources from watersheds and their transport to the stream. This spatial information can be used to assess the service of nutrient retention by natural vegetation. The retention service is of particular interest for surface water quality issues and can be valued in economic or social terms. Output: kilograms of nutrient retained in the area.
- Sediment Retention (SR): the sediment delivery model maps diffuse sediment generation and its delivery to the stream. The information is estimated using the universal equation of erosion (USLE). This spatial information is of particular interest for reservoir management and instream water quality, both of which may be economically valued. Output: tons of soil retained in the area.
- Crop Production (CPR) and Timber Production (TP) are not modelled using the InVEST algorithms since in the SAM4CP research it has been commonly decided that the proxy of these ecosystems are the price of agricultural land (for the different agricultural configurations) and the economic value of timber production for each kind of woodland. Output: the economic value of crop production and timber production in the area (CPR).
- Crop Pollination (CPO): the pollination model focuses on wild bees as a key animal pollinator. It uses estimates of the availability of nest sites and floral resources within bee flight ranges to derive an index of the abundance of bees nesting on each cell on a landscape (i.e., pollinator supply). It then uses floral resources, and bee foraging activity and flight range information to estimate an index of the abundance of bees visiting each cell. Output: average number of pollinator species per pixel in the area [13].

If the operator charged the digital LULC of an area of analysis then Simulsoil will automatically make a simultaneous computation of the ES delivered avoiding the so-called “edge-effect” adding a buffer zone around the user’s land use of 300 meters.

Despite the great innovation, Simulsoil presents several limitations that the user should consider during its utilisation. The algorithms of Simulsoil are mainly based on InVEST software processes 3.2.0, while the new releases of InVEST models are now available which overcomes the several flows and weaknesses of the previous version. Biophysical pixel quantities or indexes are converted into economic values through necessary “parametric avoided costs” for each ES. These values should be used not as an absolute reference of the ES delivery ratio (or value) rather than to compare the initial value to a predicted one. Simulsoil performs at its best when is used for a comparative analysis between alternative LULC scenario indicating which is the configuration that tends to maximise the ES delivery.

2.2. *The context of study*

The municipality of Collegno is comprised in the territory of the Metropolitan City of Turin adjacent to the compact city of Turin and is characterised by a morphological continuity of the dense and highly sealed urban development of Turin. It is bordered by Turin (East), Rivoli (West), Pianezza and Venaria (North) and Grugliasco (South). It spans 18,12 Square Km with a total population of 50 thousand inhabitants. The city is located along the pre-Alpine Susa Valley (Dora Riparia River) in the west axes from Turin to France (Chambery-Grenoble-Lyon-Paris). Half of the municipal area is composed by agricultural land (50%) which is distributed in the northern and eastern part of the territory, while the 36% is then formed by urban areas (built-up land and urban green areas) which occupy the southern part of the territory that is a part of the stripped urban systems of the low plain Susa Valley.

The territory is densely infrastructured by primary and secondary road accessibility: Highway A55, Corso Francia, plus the railroad system Turin-Mondane that divides the ancient built-up system and the recent expansion. As regards the built-up system, the Public Administration set up an Urban Regeneration Program called “Collegno Rigenera” which has been developed accordingly with the Regional Law n. 20 of 2009. The program has been focused on the renewal of the obsolete, dismissed or semi-abandoned brownfields of the city with the following targets:

- Qualify the city as “Collegno Social Town” with the intent to pursue social equality increasing the public city, the facilities and the quality of peripheries;
- Re-design the city in some parts, augmenting the aesthetic quality of buildings and greening the urban areas;
- Reduce the impact and fragmentation due to physical infrastructures, promoting the walkability by pedestrians and slow mobility in the city.

2.3. *Ecosystem Service Assessment*

In this study, Simulsoil has been used to set-up an ES assessment of a regeneration area of Collegno to see how different LULC configurations affects ES capacities. To make such an evaluation, a famous brownfield of the city has been used as test site: the area namely “Ex acciaierie Mandelli” which has been one of the most important places of the city for the production of iron. It is an ex-metallurgic plant wholly included in the semi-dense built-up system of the contemporary city thus it is suitable to see if the utilisation of ES as a measure of the quality of different land use project should realistically support the urban design at local scale. Usually, ES biophysical assessment is used i) at the landscape level (which is the right scale to see how the interaction of flows between provision and demand is solved) and ii) only for analytical purposes. In this study, the challenging use of ES assessment has been employed to see if Simulsoil is sensitive to changes in LULC also at the site-level scale and how the evaluation can be used to determine a suitable land use allocation.

To do so, five virtual land use scenarios were created (hereafter namely t0, t1, t2, t3, t4 and t5) using an editing session with ESRI ArcGIS 10.6, then the polygons were classified accordingly with Simulsoil

rules, and finally, we run the software which generated eight output for each scenario. We exported the results in MS Excel, and then we analysed the results. The following figures represents:

- T0, the actual land use, which is the digitalisation of the actual land use situation;
- T1, PRG (the Italian urban plan) transformation, which is the urban design simulation of the already planned transformation in the up-to-date Masterplan and is alternative to T0;
- T2, Collegno Rigenera, which is the urban design simulation of the alternative project designed according to the guideline rules of the Strategic Plan “Collegno Rigenera”;
- T3, Alternative Transformation (A), which is the urban design simulation of the project presented to the Municipality by the owners of the area;
- T4, Alternative transformation (B, ES maximization), which is the urban design simulation of the project that on the base of the abovementioned simulations try to maximize the ES delivering capacity using a proper rule of transformation (augment the quantity of permeable green public and private areas and increase the higher of the buildings).

It is notable that, despite the last version (which is an autonomous prefiguration), all the other urban design configurations are realistically designed according to with the land use prescriptions, thus reproducing a real design of what should happen to ES if one of the project will be selected in the future.



Figure 1. T0 Actual Land Use



Figure 2. T1 PRG transformation



Figure 3. T2 Project Collegno Rigenera



Figure 4. T3 Alternative transformation (A)



Figure 5. T4 Alternative transformation (B, ES maximization)

3. Discussion

The results obtained with the scenario simulations previously described allowed to argue that the evaluation method of urban transformation projects through ES mapping can be a useful support tool for the evaluation of urban regenerative interventions.

The comparative assessment is synthetically represented by the table that compare the output of each land use scenario.

Table 1. ES quantification in the Mandelli area

	T0	T1	T2	T3	T4
SDR	313,164	312,189	312,408	313,070	313,247
WY	186,805	190,045	195,797	195,305	196,910
CPO	0,000420	0,000421	0,000421	0,000423	0,000425
HQ	0,095	0,094	0,099	0,100	0,103
TP	-	-	-	-	-
CPR	15.941,080	18.418,410	15.941,080	15.941,080	15.941,080
CS	2.140,223	2.202,891	2.323,065	2.313,049	2.345,696
NR	-	-	-	-	-

Values in the cells reflect the output indicators (indexes or absolute values, see chapter 2) of the Mandelli area and its near surrounds included in the assessment by Simulsoil; thus the overall biophysical value displayed is higher of the exact surface of intervention. Nevertheless, using the automatic output of Simulsoil comparatively is of great help to see if the trend, instead of the absolute value, is increasing or decreasing the ES performance. In this view, the results of the table should be evaluated.

First of all, none timber production nor nutrient retention displays significant values in the area of study since the site is not subjected to any productive use while any diffuse contamination comes from Nitrates. The Crop Pollination value has several decimal numbers to make visible the slight changes between scenarios, while for the others the third decimal number is enough to appreciate differences in ES provision.

Crop Production's value remains the same among the different scenarios because there isn't a specific land use change in the area of study (that includes the transformation area plus its buffer) while all the others reach the best performance at T4 thus the Alternative transformation (B).

SDR steadily increases its value across the scenarios, meaning that in such a configuration of the plot the retention of sediment catches the better results. This specific ES is mainly dependent on the elevation of the terrain and the run-off index determined by soil properties. It is not easy to find a right property to follow for urban design guidance; nonetheless, the higher is the open green area not subjected to anthropic erosion (e.g. agriculture) the more an urban configuration will reach a higher SDR performance.

WY reaches its maximum value at T4, but shows a slightly decrease between T2 and T3 because even if the quantity and type of green areas in the two configurations are the same, T2 concentrate the open space in the northwest vertices of the area providing a little higher result in terms of water retention compared with a more fragmented distribution of the green space. This simple rule confirms the old ecological rule that the concentration of the green space provides a better environmental performance if compared with a fragmented distribution.

The above trend is not confirmed by CPO which increases its value among T2 and T3, reaching the best value at T4. This result proves that the suitable environment for pollinators is the ones that distribute equally small patches that are used as potential nesting sites for different kind of pollinators. The size of patches depends on the type of pollinator, but in this case, the model runs with an input dataset that considers 48 species with different range size of flight

The value of HQ remains quite low in all configurations (if compared with the medium HQ value in Collegno which is 0,277), nonetheless its trend is nonlinear: between T0 and T1 there is a decrease in amount that is explained again by the rule of landscape ecology that state the decay of environmental values in the fragmentation of patches. The more an area concentrates its green, the more the interaction between sources of habitat and sources of threats is limited increasing the overall Habitat value. This rule explains why between T0 and T1 HQ decreased. From an urban design perspective, a suitable solution is to reduce interferences between sources of noise and green areas limiting the effect of threats to ecosystems.

As regards the CS, here again, a nonlinear trend is registered. Between T2 and T3 the performance decreased, reaching the maximum in T4. This regulative service displays a similar pattern to WY, meaning that best Carbon storing results are achieved by land use prefiguration that concentrates the porous soil and green areas in big patches of the plot.

4. Short conclusions

Ecosystem services analysis as part of urban regeneration allows to recognise the qualities of the ecological functions that depends on the urban design composition: depending on how the area that requires transformation and regeneration is laid out, it is possible to recognise the interaction between land uses, evaluate them and finally identify the urban composition that maximises the biophysical values of quality. In this sense, the assessment through ES mapping proves to be a useful tool supporting the evaluation of regeneration projects at urban scale. Therefore, the introduction of methodologies based upon a tool (Simulsoil) introduces technical elements that aid the decision-making during town planning and the design of individual projects: as the formal composition of land uses in the area change, the ES provision display a change accordingly, which indicates that the use of maps representing various scenarios is valid and interesting.

Even if with this assessment has been used in a single area, the case study was useful in testing the assessment method proving usefulness when interpreting circumstances at a local level, allowing us to bring into relation all the areas of transformation and regeneration so as to verify the impact on the entire district and inter-district urban system.

Summing up the results obtained by this empirical assessment, hereafter some remarks are reported:

- not all ES behave equally thus a project must select ES and finalise its design according to with a limited number of ES;
- ES can effectively be used to support urban design prefiguration at local scale indicating how to implement better solutions;

- Simulsoil is a powerful and reliable tool that should help administrator and urban designer or planners to increase the sustainability of urban transformations.

Therefore, it is interesting and effective the use of representative maps of different scenarios. Regeneration means steering the project not only towards the improvement of efficient urban morphology and the quality of building but also towards the environmental and ecosystem quality of the entire soil-settlement structure. With this in mind, it is possible to work on the thematic accuracy of the cartography and integrating knowledge of other disciplines in the "ideal scenario", including the energy efficiency of buildings, the artificial materials of land coverings, etc. A further significant achievement consists in the fact that the tried and tested method is characterized by its replicability and applicability to different urban contexts.

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